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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

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Improvements relating to velocity extraction

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IMPROVEMENTS RELATING TO VELOCITY EXTRACTION

This invention concerns improvements relating to velocity extraction in the field of radiation pulse echo detection. More particularly but not exclusively, this invention concerns extraction of the velocity of a target from the returns.

Radiation pulse echo detection systems, such as radar, transmit a set of one or more coherent strings of pulses (coherent bursts) which are reflected by objects. The echoes of pulses are used to detect and locate distant objects.

Conventionally, a surveillance radar would estimate the target radial velocity using multiple estimates of the target range taken at different times. It is now common practice to filter the returns to remove clutter returns (those returns from items not of interest), leaving any returns from moving items of interest relatively unaffected. This is known as Moving Target Detection (MTD) or Moving Target Indication (MTI). Such schemes can be modified using multiple filters to obtain some measure of target radial velocity but suffer from problems due to large clutter returns 'spilling' into adjacent filters, thereby producing erroneous velocity measurements.

One of the main tasks of modern radars and sonars, is to identify and track moving targets. The accuracy of tracking is greatly enhanced if the range ambiguity and radial velocity of the target input plots are known. Only plots with matching range ambiguity and velocity will then be associated with those from previous measurements thereby significantly reducing the probability of mis-association, track seduction and false track rate.

Whilst traditional filtering methods remove the clutter from the in-phase (I) and quadrature (Q) components (the first being in phase with the transmitted signal and the second in quadrature with the transmitted signal) and typically return the target amplitude, they do not easily output the target radial velocity nor the range ambiguity of the target.

The present invention aims to overcome or at least substantially reduce some of the above mentioned problems.

According to a first aspect of the invention, there is provided a method of extracting the target radial velocity from one or more coherent radiation pulse

The bursts are optionally internally coherent but mutually incoherent. This gives an improved measure of target velocity, amplitude, range ambiguity and azimuth.

The fit residues from adjacent range cells in which a target was detected may be summed to obtain the target velocity and other parameters. This increases the probability of detecting targets split between range cells.

Conventional MTI/MTD filtering may be carried out before applying a function to the I-Q returns in which a target was detected. Post-detection processing of the data requires a lower processing capacity than pre-detection processing.

Optionally, post-detection processing is used in combination with pre-detection processing to limit the range cells processed to increase efficiency.

It is to be appreciated that the present invention may be embodied in software. Accordingly, the present invention extends to a computer program element comprising program code for configuring a programmable device apparatus or system to implement the above described method. Suitably, the computer program is stored on a carrier medium.

Further, the present invention extends to a data processing system or apparatus adapted and arranged to implement the above described method.

Preferably, there is provided a data processing system comprising a transmitter; an antenna; a receiver; signal processing means; an I and Q component splitter; an analog-to-digital converter, and processing means to fit a predetermined function to the I and Q components.

The invention will now be described by way of example and with reference to the accompanying drawings, in which:

Figure 1 is a flowchart illustrating the steps involved in a method embodying the invention.

Figure 2 shows a typical return in I-Q space.

Figure 3 is a flowchart of a variant of the method shown in Figure 1.

Returning to Figure 1, a curve constituting a simple low order polynomial in I and Q model of the clutter return, and a helical model of the target return is therefore fitted (step 108) to the sampled data to describe the returns assuming a target with a guess velocity is present together with clutter.

The fit to the sampled data is optimised (steps 108a – e) in a least squares fashion to minimise the error value, or residue, ε, given by

$$\varepsilon^2 = \sum_{b}\sum_{m=0}^{\gamma}\left(\sum_{n=0}^{\alpha}\left(I_{b,n} + iQ_{b,n}\right)t_{b,m}^{n} + \left(\sum_{p=0}^{\beta} a_{b,p}t_{b,m}^{p}\right)\exp\left[i\left(\omega_b t_{b,m} + \phi_b\right)\right] - \left(Isample_{b,m} + iQsample_{b,m}\right)\right)^2$$

with respect to velocity v, where:

$\omega_b = \dfrac{2v\Omega_b}{c}$;

Ω_b is the frequency (in radians per second) of the transmitted signal for burst b;

c is the speed of the signal propagation;

$\left(\sum_{p=0}^{\beta} a_{b,p}t_{b,m}^{p}\right) = A_b$ is the best estimate of the mean amplitude of the target at time t, seen in burst b;

$Isample_{b,m}$, $Qsample_{b,m}$ are the in-phase and quadrature components of the measured signal for pulse m in burst b;

$I_{b,n}$, $Q_{b,n}$ are the best estimate of the components of the measured signals due to the clutter seen in burst b, and

ϕ_b is the phase at the start of burst b.

The best fit target radial velocity is obtained (step 110) and other target parameters are derived (step 112), for example the target amplitude is extracted from the radius of the helix. The return strength is compared (step 114) with a threshold target return strength which is chosen to produce a desired probability of false detection.

Integrating several bursts together improves the detection probability for a target. The number of bursts over which summing occurs is referred to as the

For each partial plot (i.e. detection) in the cluster, the ratio of the mean residue to the minimum residue is the mean return power-to-noise ratio for the target in that cell. By weighting the radial velocity from each cell in the cluster by the mean return power-to-noise in that cell, summing all the weighted velocities and dividing by the sum of the weights, the weighted mean radial velocity is obtained (step 118). This is a better estimate of the radial velocity than a simple mean of the velocities as it gives greater weight to those velocities that have better signal-to-noise ratios and thus accuracies.

The burst parameters are averaged within the clusters to give the cluster parameters (step 120) and the parameters are outputted (step 122).

Optionally, the residues from adjacent range cells with bursts that cross the detection threshold are summed (see Figure 3; where the final two digits of the numbered steps are the same as those in numbered steps beginning with a '1' in Figure 1 the steps are equivalent, but not necessarily identical). As each burst is processed, detections are either declared or not for each range cell and the residues stored for those bursts with detections (step 330). The residues for each velocity step are summed (step 332) and the minimum residue found (step 334).

The target radial velocity and other parameters are obtained (steps 336, 338) from the new summed residue, i.e. summation takes place across the partial plots, not across the integration window. The original (partial plot) detection threshold for target strength at step 314 can then be quite low with a high plot detection threshold applied (step 340) to the summed data to provide the required probability of false plot detection. The lower original threshold at step 314 enables smaller targets to be detected, although with a higher probability of false alarm. The higher post interaction threshold at step 340 re-establishes the lower probability of false detection. As more bursts are integrated together, true targets that are split between range cells, for instance, integrate up and have a higher probability of detection.

detection processing reduces the computing power required. The post-detection processing method involving plot collapsing before the calculation of residues (Figure 4) is preferred to the post-detection processing method involving the calculation of the weighted mean radial velocity (Figure 5) as more bursts are included in the calculation so the likelihood of target detection is increased.

It is more efficient to discard those cells which clearly only contain noise, before carrying out the velocity extraction processing. This extra level of processing can reduce the processing load further downstream by significantly reducing the number of cells which receive the full pre-detection processing.

By applying a simple MTI filter with a low threshold (as compared to the threshold used in the processes illustrated in Figures 4 and 5) to the summed returns in all cells, the large number of cells where no target is illuminated and that clearly only contain clutter or noise and that have a very low probability of containing a target as seen from their spectral content are eliminated. In this manner, more real targets are detected and less false targets are found, compared to the processing methods shown in and described with reference to Figures 1, 3, 4 and 5. Examples of such methods are illustrated in Figures 6 and 7.

In the method shown in Figure 6, conventional MTI/MTD filtering is carried out (step 650) using a reduced threshold, on the I and Q components of the echo returns. The use of a reduced threshold increases the likelihood of target detection. The I and Q components for the range cells with bursts where detections occur are stored (step 646) before conventional plot collapsing methods are used (step 616) to detect clusters. I and Q dependent terms of residue are calculated (step 608a) for each burst in a group of adjacent partial plots (in each 'cluster' of detections) as a function of velocity. For each burst the residue is calculated (step 608b) and stored (step 608c) for each velocity step. The residues are then summed (step 608d) across all bursts included in the plot. The minimum residue is found (step 608e) and the target radial velocity and other parameters determined (steps 610, 612). The target return strength is compared to a threshold value (step 614) and the parameters are

sufficient return strength for detection to occur on the basis of a single burst then appear as detections in up to as many different locations as there are bursts integrated. Current methods of dealing with this problem, commonly known as ambiguous range trap (ART) methods suffer from a number of problems, most notably the blanking of range cells where ambiguous targets appear to be and therefore the erroneous deletion of cells with real targets present.

The method in accordance with this invention provides a means, not only of reliably identifying when the returns in the burst come from an ambiguous range target, but also of obtaining the order of ambiguity of the target.

The target range ambiguity can be estimated by considering whether a better fit to the data would be obtained by assuming that one or more of the initial returns do not lie on the helix. A target is a zero order ambiguous target (i.e. an unambiguous range target) if the first transmitted pulse is received before the second pulse is transmitted. Thus, for a zero order ambiguous target, the return from the first pulse would contain a return from the target and lie on the helix. An ambiguous range target (one with an ambiguity order higher than zero) would not have any signal from the target contained in the first received pulse and thus the received signal would lie on the axis of the helix. The ambiguity order n is given by the number of first received pulse signals lying on the axis of the helix, only the subsequently received signals lying on the helix itself.

When it is known that only a single or at least a very sparse set of targets is present, or where the bursts being integrated together all have the same PRI (although they may have different transmission frequencies) it is possible to carry out a simple minimising of the residue with respect to ambiguity and velocity.

In the latter case, when all the bursts use a common PRI, the previously described processing in any of the variants may be used with the addition that the residues are calculated for each of the possible range ambiguities of the target. The target velocity and range ambiguity is found simply by determining

ambiguities around the most likely ambiguity order and summing the residues across the bursts in the integration or plot window (depending on the method of combining the bursts used), then seeking the deepest minimum from this limited set of possible target locations, the most likely velocity, position and other target parameters can be extracted from the data. The most likely azimuth may possibly also be extracted.

For those processes that involve pre-detection processing, such as illustrated in Figures 1 and 3, the range ambiguity of each burst is determined (step 112 and 312 respectively) and bursts with returns showing targets that form clusters in range and/or range rate space, as determined from the extracted range ambiguity, are then combined. In the former case, where clusters are formed in range, the velocity is determined, on the assumption that only one target is present, by processing all bursts with returns above the detection threshold at that range to extract the best fit velocity and mean return strength. In the latter case, where clusters are formed in range rate space, only bursts with velocities that unfold to a common velocity are included in the processing. This works best when there is a high probability of two targets with differing velocities, spatially unresolved, at the same range.

For processes that involve post-detection processing, the bursts included are those involved in the detection, irrespective of whether their range ambiguities match, i.e. the range ambiguity is solved at the same time as the velocity is extracted from all contributing bursts. In the processes shown in Figures 4 to 7, steps 408b to e, 508b to e, 608b to e and 708b to e are replaced with steps 8b' to 8e', shown in Figure 8. For each burst and possible range ambiguity, the residue is calculated (step 8b') for each velocity step. The residues are stored (step 8c') and summed (step 8d') (across bursts included in the plot) for the possible ambiguities for each detection. The minimum residue is then found (step 8e') across both range and velocity (at each range ambiguity the velocity corresponding to the minimum residue will be different).

Alternatively, in Figures 4 to 7, residues can be determined in all range/azimuth cells out to the maximum possible ambiguity for all range cells with detections for all bursts over some sector. The use of a fixed sector width

The azimuth of the target (the angular direction of the target from a defined direction, e.g. north, in a horizontal plane) is then calculated (for rotating radars only) by taking the ratio of the rate of change of target returns strength to returns strength for each coherent burst included in the process and fitting the resultant normalised gradients to the beam shape. The resultant ratios are used to derive the polynomial

$$\sum n\left(\frac{a_n}{a_0}\right)t^{n-1} = 0$$

the solution for which gives the time at which the antenna pointed at the target. From that time, the azimuth of the target is determined as the azimuthal direction of the antenna at time t.

The crossing rate of the target, i.e. the rate at which the target crosses the field of view of the antenna, can also be determined from the beam shape. This can be combined with the radial velocity to give the target velocity.

An embodiment in accordance with another aspect of the invention is shown in Figure 9. A data processing system 60 comprises a transmitter 62; an antenna 64; a receiver 66; signal processing means 68; an I and Q component splitter 70; an analog-to-digital converter 72; a digital filter 74 and processing means 76 to fit a predetermined function to the I and Q components. The transmitter 62, connected to processing means 76 (connection not shown) or other processing means (not shown), emits coherent radiation bursts from the antenna 64. Radiation echo returns of the pulse bursts are received from a remote scene by receiver 66. Signal processing means 68 may include, for example, RF filtering to remove out of band signals, automatic gain control (AGC) to reduce the gain when strong signals are received to prevent overload, beam forming to focus the radar to look in one specific direction, jamming null steering to reduce the antenna gain in the direction of jammers or pulse compression to allow the transmission of long low mean power signals that can be compressed on reception into a short high power return. The echo returns are processed into I and Q components by the splitter 70 either before or after processing by the analog-to-digital converter 72. The returns are measured at

described above). A more computationally efficient method calculates the residues at the 'Nyquist' frequency (the cut-off frequency above which a signal must be sampled in order to be able to reconstruct it) and uses an interpolation technique about the minimum calculated point to determine the actual minimum and corresponding velocity.

Where two or more minimum residues are found to be of similar value additional processes can be used. This processing may either flag that there is a potential problem with the extracted parameters (including velocity) or pass the parameters and velocities for all the relevant minima to subsequent radar processing (track extraction). This approach minimises the errors due to velocity ambiguities and multiple targets in the same range cell on the extracted velocity.

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CLAIMS

1. A method of extracting a radial velocity characteristic of a target from one or more coherent radiation pulse bursts comprising the steps of:

   (a) receiving radiation echo returns of the pulse bursts from a remote scene;

   (b) processing the echo returns into in-phase (I) and quadrature (Q) components;

   (c) measuring returns at intervals to provide sampled data

   (d) applying a predetermined function to the I-Q returns;

   (e) modifying the predetermined function to match the sampled data as a function of velocity; and

   (f) determining the target radial velocity in dependence upon said modification step of the predetermined function.

2. A method as claimed in Claim 1 wherein step (d) comprises fitting a curve to the I-Q returns and step (e) comprises optimising the fit to the sampled data as a function of velocity in a least squares fashion.

3. A method as claimed in Claim 1 or 2 wherein a model of clutter return is provided for use in steps (d) and (e).

4. A method as claimed in Claim 3 wherein the model of clutter return is a low order polynomial function in I and Q.

5. A method as claimed in any of the preceding claims wherein the echo returns are measured at non-equi-spaced intervals.

6. A method as claimed in any of the preceding claims wherein the pulse bursts are transmitted at a frequency which is changed between successive pulses.

7. A method as claimed in any of the preceding claims wherein each pulse burst consists of multiple pulses transmitted at irregular intervals.

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ABSTRACT

IMPROVEMENTS RELATING TO VELOCITY EXTRACTION

A method of extracting a radial velocity characteristic of a target from coherent pulse bursts comprising the steps of applying to data a 'best fit' model of the echo returns from a target in the presence of clutter to obtain a residue (error) value and minimising the error value by a predetermined method to give the best fit value for the target radial velocity. The method enables more information to be retrieved from coherent bursts than conventional methods and therefore greatly enhances performance of radiation pulse echo detection.

Figure 1

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FIGURE 1

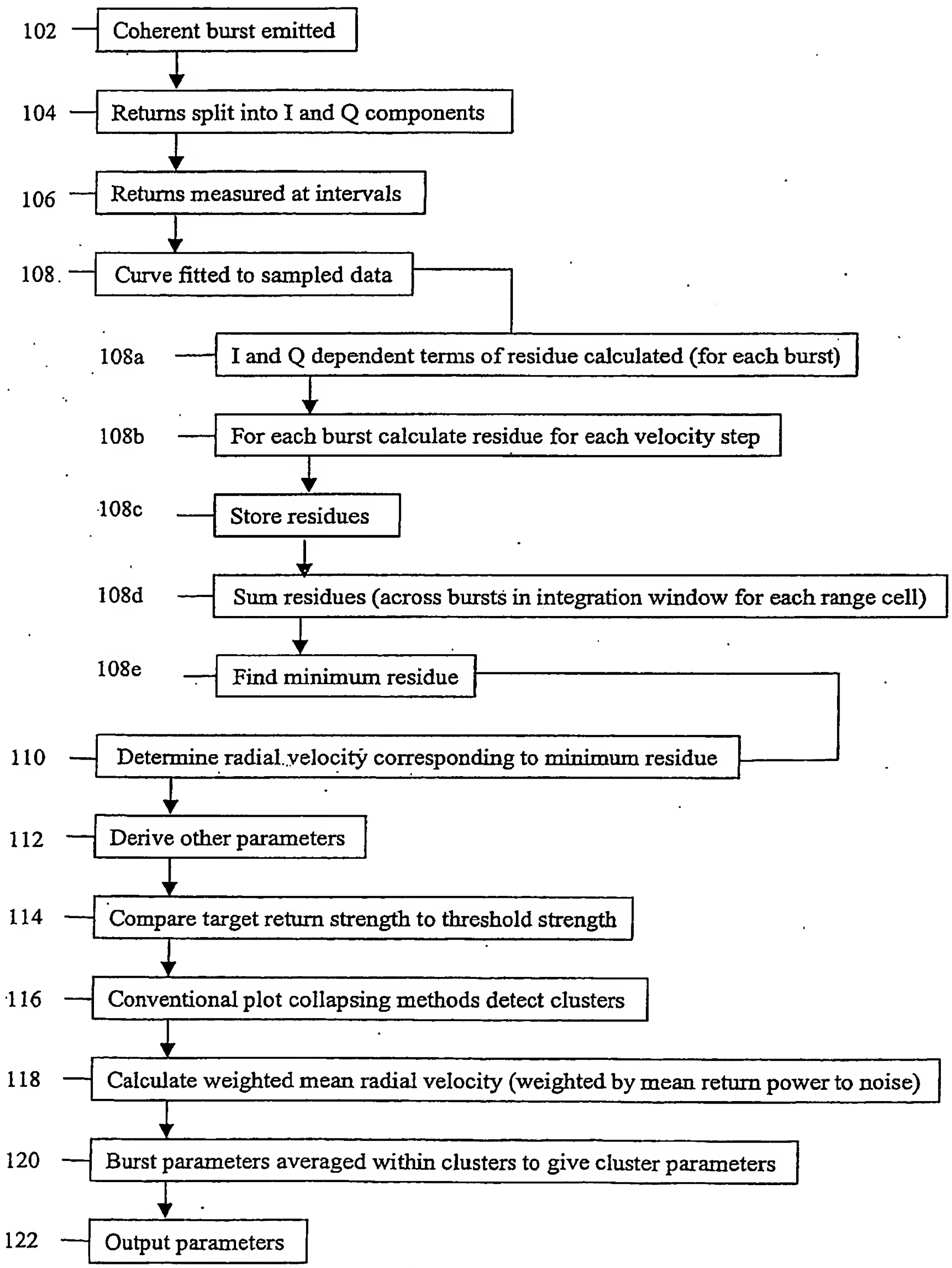

FIGURE 3

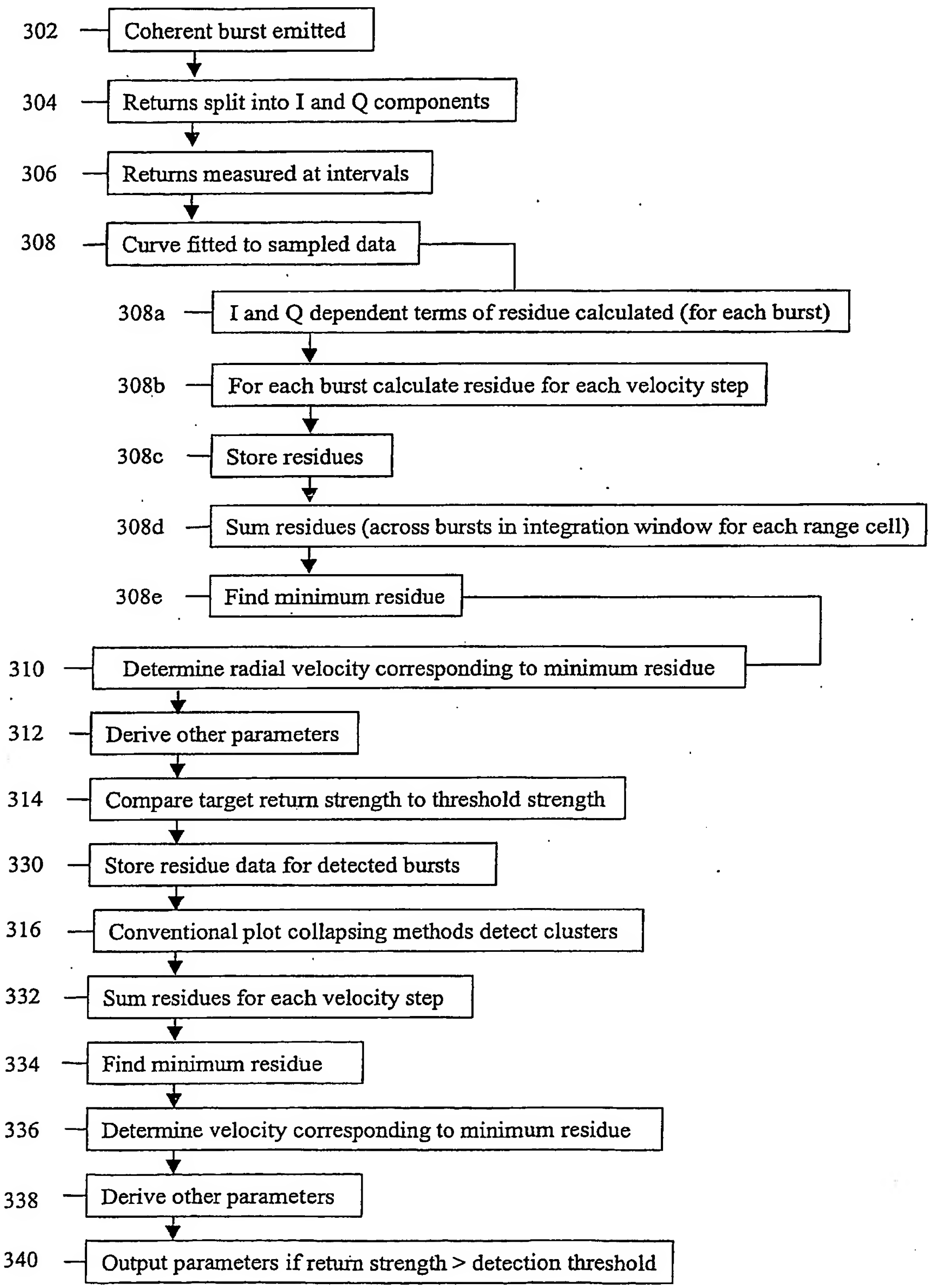
302
Coherent burst emitted
304
Returns split into I and Q components
306
Returns measured at intervals
308
Curve fitted to sampled data
308a
I and Q dependent terms of residue calculated (for each burst)
308b
For each burst calculate residue for each velocity step
308c
Store residues
308d
Sum residues (across bursts in integration window for each range cell)
308e
Find minimum residue
310
Determine radial velocity corresponding to minimum residue
312
Derive other parameters
314
Compare target return strength to threshold strength
330
Store residue data for detected bursts
316
Conventional plot collapsing methods detect clusters
332
Sum residues for each velocity step
334
Find minimum residue
336
Determine velocity corresponding to minimum residue
338
Derive other parameters
340
Output parameters if return strength > detection threshold

FIGURE 5

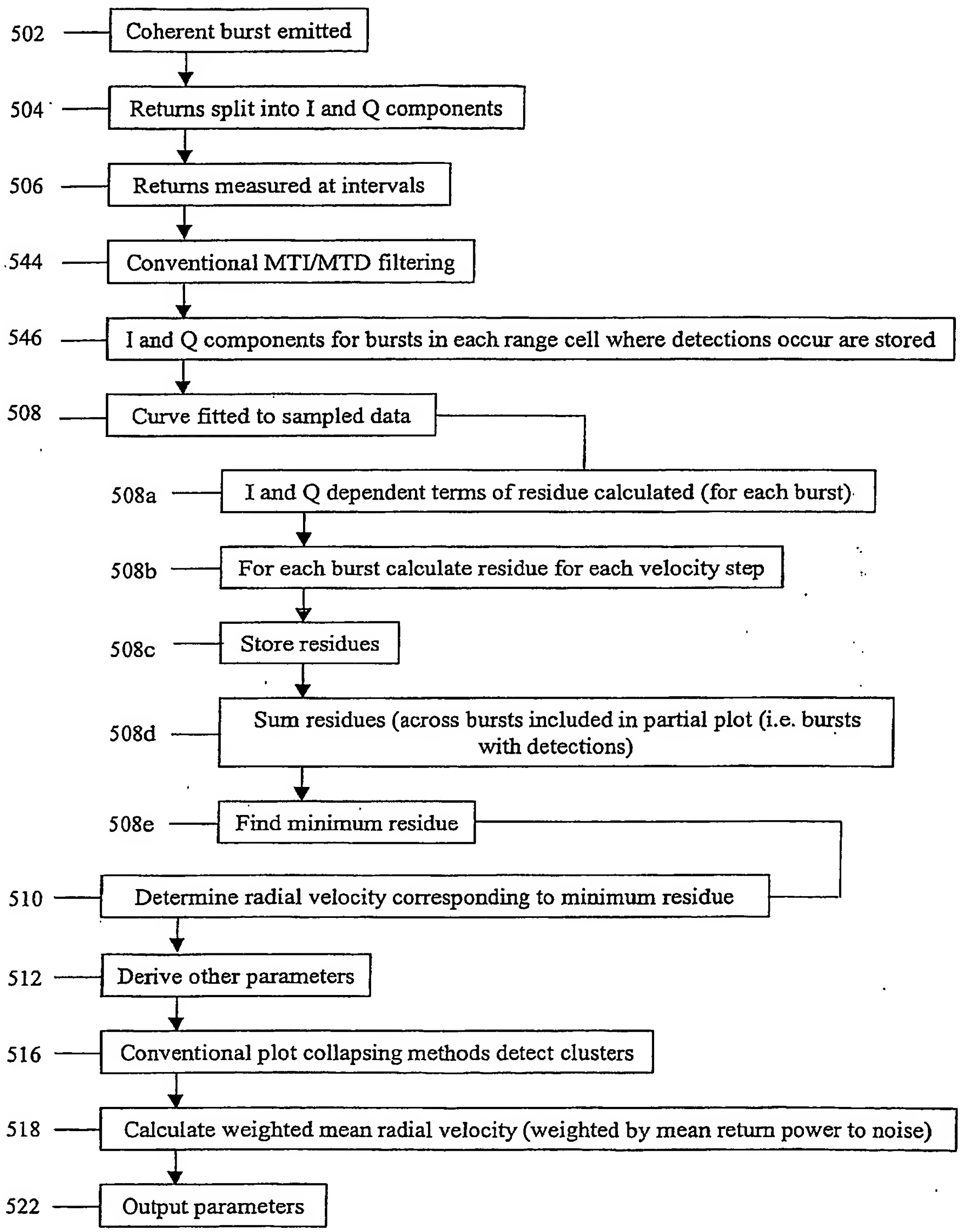
502
Coherent burst emitted
504
Returns split into I and Q components
506
Returns measured at intervals
544
Conventional MTI/MTD filtering
546
I and Q components for bursts in each range cell where detections occur are stored
508
Curve fitted to sampled data
508a
I and Q dependent terms of residue calculated (for each burst)
508b
For each burst calculate residue for each velocity step
508c
Store residues
508d
Sum residues (across bursts included in partial plot (i.e. bursts with detections)
508e
Find minimum residue
510
Determine radial velocity corresponding to minimum residue
512
Derive other parameters
516
Conventional plot collapsing methods detect clusters
518
Calculate weighted mean radial velocity (weighted by mean return power to noise)
522
Output parameters

FIGURE 7

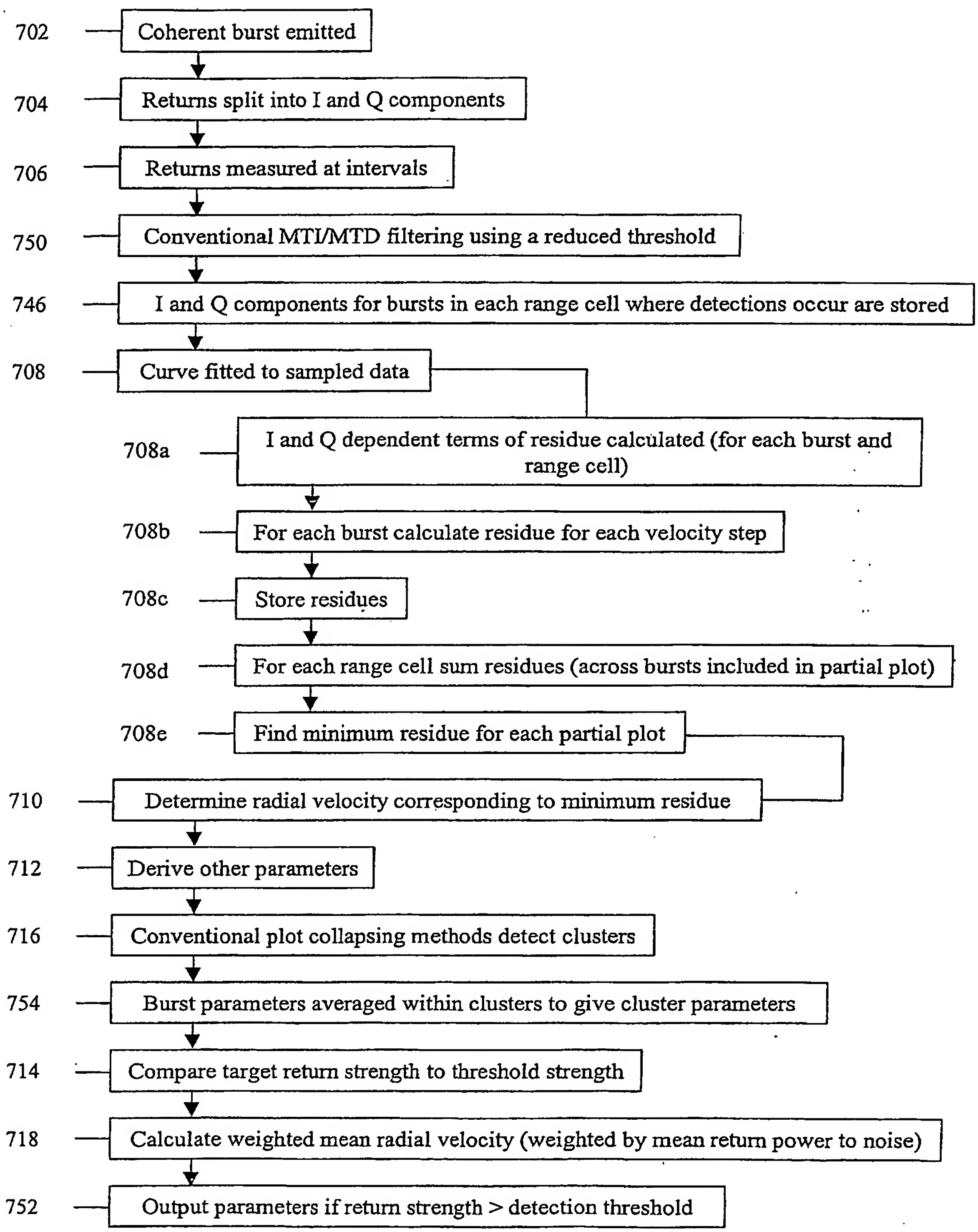
702
Coherent burst emitted
704
Returns split into I and Q components
706
Returns measured at intervals
750
Conventional MTI/MTD filtering using a reduced threshold
746
I and Q components for bursts in each range cell where detections occur are stored
708
Curve fitted to sampled data
708a
I and Q dependent terms of residue calculated (for each burst and range cell)
708b
For each burst calculate residue for each velocity step
708c
Store residues
708d
For each range cell sum residues (across bursts included in partial plot)
708e
Find minimum residue for each partial plot
710
Determine radial velocity corresponding to minimum residue
712
Derive other parameters
716
Conventional plot collapsing methods detect clusters
754
Burst parameters averaged within clusters to give cluster parameters
714
Compare target return strength to threshold strength
718
Calculate weighted mean radial velocity (weighted by mean return power to noise)
752
Output parameters if return strength > detection threshold

FIGURE 9